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BATTLE
An Expert Decision Aid for Fire Support Command and Control

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) We have implemented an expert consultant system (called BATTLE) to aid in the assignment of a particular set of weapons to a set of targets, given a battlefield situation. BATTLE illustrates the application of several artificial intelligence techniques to a decision aid for the Marine Corps. A pruned tree traversal, though not guaranteed to discover the "optimal" solution, will attack the problem of assigning targets from the viewpoint of finding a globally optimal assignment plan. This should be an improvement (Continues)		

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on present algorithms that optimize weapon to target assignments only in a local sense. Inference networks allow BATTLE to consider many relevant environmental conditions while making its decisions. The use of dynamic inference networks allows military experts to update the program and keep it consistent with changes in military doctrine without actually altering the computer code. These design considerations should be useful in some future version of the Marine Integrated Fire and Air Support System (MIFASS), the current decision aid under production for the Marine Corps.

CONTENTS

BATTLE
AN EXPERT DECISION AID FOR
FIRE SUPPORT COMMAND AND CONTROL

INTRODUCTION

Decision aid technology is one of the more rapidly expanding uses of computers. One such aid, the Marine Integrated Fire and Air Support System (MIFASS) will "provide for the establishment of fire and air support centers to plan, integrate, direct, and coordinate the fires of supporting arms" [4, pgs. 2-19]. An algorithm for use in the MIFASS system to direct fire power was developed at Oklahoma State University (1975-1977). The OSU algorithm attempts to discover good fire support allocation schemes through an iterative technique, always optimizing the weapon being selected for the next most crucial target [1,2]. Selection of the next target to be assigned is determined by a heuristic formula.

Implementation of the Oklahoma State University algorithm in MIFASS was left to the Norden Corporation. Norden criticized the Oklahoma State University system, saying that "the algorithm does not do most of the things claimed for it, and in many cases cannot be modified to satisfy those claims" [5].

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The inherent limitation of the OSU technique is that the potential targets are considered separately, rather than simultaneously. An optimal solution would consider the problem as a whole, rather than as a set of individual, smaller problems. It is probably not possible to find an optimal allocation scheme in a reasonable amount of time. The time required using a tree search without pruning would be proportional to the number of targets plus one, taken to the power of the number of weapons. Generation of a complete tree of possible weapon to target assignments, and exploration of that tree for the optimal assignment would require an unreasonable amount of computing time for a reasonable battlefield scenario. Rather we wish to investigate the possibility that applying tree traversal with pruning to the assignment tree might provide reasonable solutions to the assignment problem. This will probably require more computing time than the iterative technique developed by Oklahoma State University, and would thus have to be implemented on problems of a smaller scale.

An important part of our system, which could also be incorporated in the Norden implementation, is a dynamic set of environmental factors which might influence the effectiveness of some weapon against some target. In addition to the simple restrictions included in Norden's implementation, such as requirements for ammunition, fire time, and restricted fire zones, there may be many factors which can not be known a priori. Troop morale, for example, might be the decisive factor in a military engagement. There is no present mechanism for the inclusion of such considerations in the programs presently being developed for MIFASS.

THE INFERENCE NETWORK

We have designed and implemented an inference network modeled after the method of subjective bayesian updating found in "PROSPECTOR" [3]. This is a very flexible system which may be easily adapted by military experts unfamiliar with computer programming. An inference network may be created to deal with any sort of external condition which the military experts believe might influence the performance of weapons. Such an ability would be an invaluable asset to the MIFASS system; it would in effect allow military experts to modify the considerations used in weapon to target assignments, and keep the system updated with the latest ideas on what is most pertinant to weapon allocation decisions.

An inference network consists of nothing more than a set of associated facts (or, propositions) and the rules or links which direct their associations. The facts are related to one another in a logical order that allows propagation through the network of information, such as the probability that any particular fact is true. The inference network may involve simple tree structures or more complicated graph structures, a decision to be determined by the expert.

Facts are described by the expert in a general, propositional form. For example, "friendly-is-a-good-match-against-target". Such a fact only has meaning in a specific context, say in comparing friendly unit friendly1 against target unit target7. We say that this fact has the "context" called "both" as a shorthand for saying that

it only makes sense (e.g., has a truth value) in the context of both a specific friendly unit and a specific target unit. Some other facts need just a specific friendly unit (or, target unit) to take on meaning. Such a fact we say has context "weapon" (or, "target".) And still other facts are independant of any friendly or target unit (for example, "It is raining") and are said to have the context "global." The expert must specify the context. The "context" may be viewed as a set of variables upon which a fact depends. The variables are "typed" in that their values are restricted to particular classes, such as weapons or targets.

The system supplies the expert with a set of links for associating facts. These are the standard logical connectives AND, OR, and NOT; and one called EVD (for "evidence.") Functions are also provided with these links which propagate information through the network. The probability function provided with the AND link assigns the product of the probabilities of the antecedents to the consequent. The probability function for the OR link assigns the product of the complement probabilites of the antecedent to the complement of the consequent. The probability of the consequent of NOT is simply the complement of the probability of the antecedent.

The EVD (evidence) link is updated with the subjective Bayesian method described by Duda in [3]. This type of link provides a more symmetrical mechanism for the propagation of probabilities than either the AND or OR link. The AND link will tend to keep the consequent probability low. It is very easy for a single antecedent of the AND link to reduce the consequent probability. Similarly, the

OR link will tend to keep the consequent probability high. A single antecedent of an OR link may greatly increase the consequent probability by itself, but will have very little ability to lower the consequent probability. The EVD link is a more stable type of situation. Consequent probabilities tend to remain around the prior level, and are influenced equally in both directions.

Each antecedent in the EVD link may add or detract from the consequent probability individually, regardless of the state of the other antecedents. In AND links, if the probability of one antecedent is very low, none of the other antecedents can have a great influence. Likewise, if one antecedent to an OR link has a high probability then none of the other antecedents can have a great influence. EVD links are more responsive to conflicting antecedent probabilities. If one antecedent has a high probability and another antecedent has a low probability, their influences will tend to cancel.

Sometimes, however, the expert will find that he must define his own links. Since links are functionally defined, an expert can define a new link type by merely writing LISP functions for propogating information, such as probability, from the antecedents to the consequent. The BATTLE system does, in fact, contain a number of such special purpose links.

USING THE NETWORK

The user of the network, as opposed to the expert creator, has available two modes of inputting data. The "question" mechanism produces a system-directed dialogue with the user, while the "volunteer" mechanism allows the user wno has information on particular facts to directly enter it. The volunteer mechanism is relatively straightforward. Once the information is volunteered, its effect is propogated up all appropriate links. The question mechanism, however, is more complex. Before describing it, we need to define some properties and values assigned to facts in the network.

For each particular context, each fact may at some point during the execution of BATTLE acquire the properties designated as "asked" and "answered". An "asked" fact has already been asked and shouldn't be reasked, although its antecedents may be asked. An "answered" fact has been either answered or volunteered by the user. It and its antecedents should not be reasked. The expert creator of the network shculd have assigned to each node the property "askable" or "unaskable." The expert expects the user to be able to provide an "askable" fact. An "unaskable" fact should be calculated by the system.

The expert should have assigned two values to each fact. One is a "prior" (or, a priori) probability of its truth or falsity. The other, "self merit", is an approximation of the partial derivative of the value of the proposition with respect to the cost of expanding

it. A large self merit value should be given to askable facts that are deemed likely to change substantially in probability, or to unaskable propositions with few antecedents. Unaskable propositions should have higher self merits than their askable counterparts in general. The most important principle in assigning self merits is that they should all be given values that are correct relative to one another. To a first approximation, a changeable fact should be given greater self merit than a more stable proposition.

In the implementation of BATTLE, when the user opts to have the system direct questioning, the "merit" system is used. Given the top consequent of a network, the system finds the proposition in that network which has the highest merit value (ie., the most "meritorious"), wherever it might be located in the network. This fact is considered by the system to have the best combination of being relatively easy to supply and relatively influential to the top consequent. The most meritorious antecedent is presented to the user first. If the merit of the most meritorious antecedent should be less than the cutoff value specified by the user, the system will inform the user that no more questions remain to be asked on this subject.

A complete description and derivation of merit is in [6]. Here we will just present its basic definition and describe its use in BATTLE. To begin with, assume for a moment that we have a general proposition tree with a top proposition G and subpropositions Gi (for i = 1 to n). Each subproposition Gi may itself have subpropositions designated Gij (for j = 1 to m). In general, an additional subscript

will indicate another level down the proposition tree. The merit of an untried proposition Gij...st is defined by the partial derivative:

$$\left| \frac{d\,P}{d\,Cij...st} \right|$$

where dP is the change in the probability of the top proposition G, and dCij...st is the cost of expanding the untried proposition Gij...st. Absolute value is used because we do not differentiate between changes in probability in the positive or negative directions. What matters to the merit is the absolute ability of node Gij...st to influence the probability of proposition G if Gij...st is expanded.

Note that this definition of merit describes in precise mathematical terms those qualities we desire most for the next proposition on the inference network which is to be expanded. A high merit states that a proposition will exert much influence on the top proposition with little cost. Low merits indicate that expansion of a proposition will have little effect on the probability of the top proposition or that the expansion will be accomplished only at a high cost.

The merit has been expressed as a derivative relating P, the change in probability of the top proposition, to the cost of expanding an untried proposition somewhere else on the proposition tree. Instead of expressing the derivative as such, we find it simpler to apply the chain rule and evaluate the derivatives of linked propositions.

$$\left|\frac{dP}{dCij...st}\right| = \left|\frac{dP}{dPi} * \frac{dPi}{dPij} * \ldots * \frac{dPij...s}{dPij...st} * \frac{dPij...st}{dCij...st}\right|$$

The last factor in this expansion is the only one involving the cost of expanding the untried proposition. It is the self-merit of that proposition and represents the ability to change the probability of the untried antecedent, per unit cost applied in expansion of the antecedent. For our purposes, we will approximate the self-merit by an expert opinion, and so we need not worry about calculating it.

To calculate merit values, the system will start at the top proposition selected by the user, examining all antecedents of that proposition. A merit value will be calculated for each antecedent, and the antecedent with the merit value of greatest absolute value is determined to be the most meritorious. If that antecedent is askable and has not been previously asked, then it is asked. If the user answers the question his response is propagated through the network to the top consequent, and the process of finding a new most meritorious question is started again after the fact just answered by

the user is marked as answered. Should the user decide to skip the question, the fact is marked as asked. That fact is then expanded, and new merit values are calculated for all the antecedents of the fact.

Thus, merit values allow the system to question the user about the battlefield scenario in an intelligent manner. This algorithm may result in skipping around the inference network, but should always ask the most important questions first, and could save the user considerable time over a classical depth-first traversal of the inference network.

THE ASSIGNMENT TREE

In the BATTLE system, there is a set of inference networks and the top consequent of each represents the effectiveness of one type of friendly weapon (eg. 105mm artillery) against one type of target (eg. an oil depot or a 155mm artillery unit.) We allow targets to be composites of more than one type, say an oil depot that is in the same camp as a 155mm artillery unit. To calculate the effectiveness of one friendly unit against the composite target, we simply add the effectiveness values of the friendly against each target component. To calculate the effectiveness of massing several friendly units against a single target, we "or" the individual effectiveness values. The "or"ed value is simply the complement of the product of the complements of the various effectiveness numbers.

Once an effectiveness value has been determined for each target that has been assigned in the planned assignment scheme, the total value for the assignment may be calculated. The effectiveness value for each target is first multiplied by the target value to produce a normalized value for the amount of destruction expected on that target. Finally, the normalized values for each of the targets are added together to produce a total effectiveness value for the entire assignment.

Presently, an assignment tree is used to explore all the possible assignment plans for the battlefield situation. Each level on the tree corresponds to the assignment of a different weapon. Thus, the number of levels on the tree is equal to the number of weapons that the system is asked to assign. The degree of the tree is one greater than the total number of targets. At each node, the various branches correspond to the assignment of that weapon to the various targets, and the last branch corresponds to leaving the weapon unassigned. At the bottom of the assignment tree all the possible assignments of friendlies to targets will be enumerated. Massing of friendlies on targets follows very naturally in this scheme. Massing on a target just corresponds to taking the same branch down from a node for more than one weapon.

It should be apparent that the size of such an assignment tree will be equal to the number of targets plus one, taken to the power of the number of weapons. This is an extremely large tree, and

it would not be practical to traverse such a tree for the average fire support assignment problem. We therefore must prune the tree during its traversal. For this purpose the fighting capacity values specified for each of the weapons is used. The fighting capacity is supposed to represent the maximum possible value to be gained by using a friendly. If at some point in the tree we find that the effectiveness of an assignment plan plus the combined fighting capacities of all the weapons from that point down is less than a value already determined for another assignment plan (the Kth best plan), the branches below that point are all pruned off. This results in a substantial saving of time during the traversal. The weapons and targets are each ordered in decreasing value to assist in this pruning process.

The various assignment plans are rated according to this computed total value. The k best assignments (where k is specified by the user) are then presented to the user and he may proceed to select the option he prefers the most. This choice will allow the user to override the computer's ranking of the options, if he so desires.

FUTURE IMPROVEMENTS

We will be looking into applying "genetic algorithms" [7] for improving the efficiency of target assignment. Also, we hope to extend the propositional nature of facts in the inference network to predicates.

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